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The digitization of meteorological information

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1. Introduction

In the last few years a great deal of work has been done in developing methods of automatic data processing now that electronic and other computers are becoming more generally available. Such computers are normally fed with basic information recorded on punched cards or tape, on which each variable parameter is represented by its value in digital form, at discrete intervals of time. As the basic measurements may not necessarily have been obtained in this form, ancillary equipment, referred to as a "digitizer", is required to translate the available information into the required sequences of numerical values. Other considerations permitting, when it is known that the values derived from a particular instrument are to be used in computing equipment, direct digitization should be "built-in" with the instrument, avoiding the labour of subsequent transmutation of the results, although existing records, either graphical or tabular, can be digitized. Recently the question of applicability of these methods to meteorological information has arisen within the Meteorological Office and this report is concerned with indicating some of the digitizing equipment that is either available or under development, and with the consideration of how it can be used for meteorological problems. Since the equipment which has been developed is in many respects suitable for general purposes it is not proposed to discuss how specific examples of meteorological information can be digitized but rather to outline the general requirements for instrumentation that digitization imposes.

The aim of digitization is to produce data, which will in general be values of some physical quantity at specified time intervals, automatically or semi-automatically, in a form suitable for further processing. There are two principal types of instrument; those which have to be read by an observer and those which record automatically, usually in the form of a curve on a chart. In the first case the observer himself plays the part of the digitizer, in producing a written record of the required quantity at predetermined time intervals. In the second case extraction of information from the continuous record must be made before it is in a suitable form for further processing; it is in fact converted to information of the first type before it can be handled. The form in which the initial data is obtained will depend on what is required of it. In the simplest case, a visual reading, followed by a straightforward tabulation of the value of the variable at specified times is all that is necessary. The data may however be required as the basis of a complex computing scheme and as such it would be convenient to provide it punched on cards, or tape, in a code suitable for direct input to the machine to be used; digitization equipment can satisfy these requirements.

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2. Digitizers

The basis of the digitization methods discussed in this report is the digitizer itself; so far two types are available, mechanical and optical. The mechanical digitizer can be a flat disc (rotating type) or a flat plate (linear type) divided into a number of concentric or parallel tracks, each of which is sub-divided into conducting and non-conducting segments. The segments are arranged so that any line perpendicular to the tracks crosses a unique pattern of conducting and non-conducting segments, the pattern being related to the position of the line and arranged so as to conform to one of several types of cyclic progressive coding. Each track is swept by a contact, and the position of the coded disc which is controlled by the measuring equipment, is uniquely expressed by the pattern of electrical impulses occurring in the contact circuits, an impulse appearing in a track circuit if the segment under the brush is conducting and failing to appear if not. The code chosen is immaterial to the form of the final result, but the most favoured number of divisions for one complete revolution of the rotating type of coded disc is 1000 (000-999) requiring 12 tracks, four for each decimal digit. A similar system is also true of the flat plate digitizer. The optical digitizer is essentially similar but instead of conducting and non-conducting segments a glass disc is used, the segments are transparent or opaque, the brushes being replaced by photocells. The primary advantage of the optical digitizer is the greatly reduced operating torque required with the absence of brush friction on the tracks.

The output from the tracks of the digitizer is taken to a decoding device which determines the form of output of the system. By appropriate design the output from the decoder can be made suitable for operating standard tape reperforators, card punchers, typewriters, line printers, computer inputs etc. The final form can be either on a binary or a decimal system of notation, the form chosen in any particular problem being determined by the nature of the subsequent operations to which the data are to be subjected. The digitizer, decoder and output taken together can be regarded as equivalent to a position indicator, giving the position of the disc (or plate) in terms of a series of numbered steps, usually 1000 steps are equivalent to full range although an optical digitizer has been quoted as having 10,000 divisions for one rotation. In some cases it is possible to do away with the digitizing disc or plate and to feed the output of the instrument directly into a relay decoder. For this to be done the output of the instrument must be arranged to be a voltage; of the order of 100 volts for full scale is required to match the operating characteristics of the relays in the decoder. The relay decoder then compares the output voltage with a reference voltage, the particular combination of relays required to achieve equality corresponds to the appropriate number in the particular code being used.

3. Handling of chart records

Equipment for semi-automatic analysis of strip chart graphical records is now on the market, and more advanced forms are under development. The simplest of these digital analysers incorporates a flat plate digitizer with 1000 divisions corresponding to full scale. It can accept charts up to six inches in width and has a scale adjustment of $\pm$ four per cent. No provision is made for non-linear calibration however. The chart is fed manually underneath a cursor linked to the contacts moving over the digitizer plate, the cursor is set on the trace by hand and "print out" of the selected value initiated by a foot switch, this sequence of operations being repeated for each reading. It is claimed that rates up to 1000 readings per hour are readily attainable and the accuracy of reading at the trace is of the order of $\pm$ .003 inches. All readings are given in the arbitrary scale of 1000, the number of divisions on the digitizer, and charts smaller than six inches only utilize a proportion of the available digits.

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A more refined set of equipment is produced by the same firm, in this case movements of the cursor operate a potentiometer giving a variable voltage. This is fed to a calibrator unit which can apply a linear scale from 1 to 18 and non-linear calibration can be approximated so that the digital output can be arranged to be in the units of the original trace. The calibrator output is fed to the digitizer unit, which has three output ranges. These, together with the 1 to 18 scaling possible in the calibrator, enable a very wide range of scales to be covered. The final output can be on electric typewriter, tape reperforation or card puncher. This reader accepts charts of up to six inches in width.

A further set of equipment is envisaged which is intended to cope with chart records up to 12 in. in width. Linear or non-linear calibration is to be accomplished in this case by graphical means at the trace reader itself, and the output will again be suitable for an electric typewriter, card or tape punch.

4. Direct digitization of information

This heading can at once be sub-divided into two classes, the first where the digitizer is physically coupled to the measuring instrument and the second where the digitizer is remote from the instrument, coupling being provided by some analogue means.

The digitizer can only be fitted directly to the measuring instrument if the instrument satisfies the following conditions:-

(i) The instrument output can be arranged to give either a rotation or a linear movement such that full scale corresponds to the full range of the digitizer.

(ii) The instrument has a sufficient power output to satisfy the torque requirements of the digitizer; of the order of 100-200 gm. cm. for mechanical types and 5 gm. cm. for an optical digitizer.

(iii) The digitizer can be adequately protected from damage due to exposure.

It is only the digitizer which needs to be physically coupled to the instrument, the decoder and output gear can be situated remotely from the measuring equipment.

In the second case where the digitizer is remote from the measuring instrument itself we have two problems to consider; firstly the conversion of the output of the measuring instrument into a form suitable for transmission and secondly the conversion of the transmitted signal into power to operate the digitizer. Instruments fitted with remote automatic recorders already satisfy the first of these requirements and, provided that the recorder develops sufficient power, the second can be satisfied. Several types of automatic self-balancing recorders either of the potentiometer or resistance type which have provision for fitting mechanical disc or plate digitizers are on the market, and the problem is really one of arranging that the measuring instrument output is suitable to operate one of these recorders. One point which should be borne in mind here is the matching of the response time of the recorder to that of the instrument, since the recorders are essentially servo-operated following mechanisms which if not properly matched may act as 'meaning' devices. In consequence the final output would not necessarily be that corresponding to the response time of the instrument itself. The accuracy of the whole system will be a function of the individual accuracies of the instrument, the following system and, finally, of the digitizer. That the digitizer operates in unit steps is not likely to be a drawback since for 1000 divisions the resolution is to the nearest digit or 1 part in 1000 - greater than can normally be obtained by graphical recording.

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One advantage of using a recorder of the above type is that a chart record may also be obtained, allowing the performance of the system to be monitored as required, an important point since if the data are put straight on to cards or tape for subsequent processing by machine, faults in the system may escape immediate notice. Chart records are also of great value in allowing rapid assessment of the results as a whole, with the identification of the more significant parts of the trace.

If the measuring instrument has a suitable output, magslips can be used to transmit the information for remote digitization. An optical digitizer with low operating torque would be necessary in this case. The permissible speeds of operation of digitizers may also determine which type should be used, figures quoted are 30 r.p.m. for a mechanical disc type and up to 5000 r.p.m. for an optical type. The speed of 'print out' limits the permissible rate of sampling. For high operating speeds maintained for limited period of time an extra piece of equipment can be employed between the digitizer and decoder. This is either a relay store or an electronic store, which can retain the information, forwarding it at a rate suitable for the comparatively slow speed of operation of the decoder and 'print out' equipment.

For meteorological purposes this is not likely to be a drawback since quoted 'print out' rates, for disc-digitizers, are of the order of 50 per second.

The initiation of the sequence of events leading to the 'print out' of an individual measurement by the digitizer attached directly or indirectly to the measuring instrument is accomplished electrically. The requisite pulse which commences the cycle can be obtained in a number of ways depending on the requirement, the most obvious being to use a clock-driven contact if 'print out' is required at constant time intervals.

For special applications, where the equipment is to be used for one purpose only, the digitizer and decoder can be arranged to give an output in the units of the quantity being sampled. Thus, for example, a digital clock has been built which shows hours and minutes directly on a visual in-line display panel. Once an equipment is specially coded it loses all its versatility and thus it may be preferable to retain output in non-dimensional form, putting calibration and scaling factors in via a programme in subsequent processing. Once the data, in some form or other, have been punched on cards or tape, subsequent processing is determined by availability of machines, the appropriate machine type being chosen for the particular operations to be performed on the data.

5. Example

So far the discussion has been in very general terms and concerned only with general requirements. In order to bring out some of the points more fully it would be as well to consider a specific example in rather greater detail than is possible in the general case. The example chosen is one for which digitization has already been suggested as a means of reducing the vast amount of labour in extracting and processing data. In a recent paper [1], apparatus to measure the vertical gustiness in the first few thousand feet of the atmosphere has been described, together with results from the apparatus attached to a captive balloon cable. It is proposed to indicate how such results might be digitized ready for subsequent processing using as far as possible the existing apparatus.

The apparatus consists of a horizontal wind vane and run of wind meter which can be attached to the cable of a captive balloon and kept pointing in the vertical plane containing the horizontal wind direction by means of a vertical additional wind vane. A light contact attached to the horizontal wind vane is arranged to sweep over a potentiometer connected into a bridge network so that the output is proportional to the angle of inclination of the wind vane to the horizontal. A pair of wires lead from the bridge to a d.c. amplifier on the ground whose output is fed to a rapid response recording milli-ammeter. The sensitive air meter operates a switch after each preset run of horizontal wind

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which switches out the potentiometer from the bridge circuit replacing it by a pair of fixed resistances which correspond to a standard angle of inclination. The final chart record appears as a record of inclination together with a short standard pulse at intervals, which serve to give a mean wind speed and form a check on the inclination trace. Digitization using one of the trace readers mentioned above is straightforward and needs no further comment.

In this example, digitization by fitting a digitizer direct to the airborne instrument is not possible because of weight limitations, the weight of the apparatus carried aloft by the balloon having to be kept to a minimum. The digitizer must therefore be operated on the ground remote from the instrument itself. Since the potentiometer gives a variable voltage output it could be connected directly into a recording potentiometer fitted with either a shaft or plate digitizer. A suitable recorder would seem to be available, one having a full scale balancing time of 0.4 seconds when operating a digitizer being on the market. 'Read out' from the digitizer could be initiated by a clock-driven switch adjusted to give a pulse at the required time intervals. The impulse from the air meter as it completes its predetermined run of horizontal wind could be transmitted down the same pair of leads, as at present, and by suitable switching initiate a record of the time intervals between impulses by means of a digital clock. 'Read out' from the clock would be passed to a storage unit for holding and printed by using the same decoder and output between 'print out' of inclination data. Since in general there will not be a closure of the run of wind contact during each of the time intervals, arrangements could be made either to repeat the previous time or to insert a symbol to avoid confusion. The final information on the cards or tape would then consist of values of inclination alternating with either the times of attaining a given run of wind, or dummy figures. The code used for output would be determined by the machine available for further processing and would determine the detailed design of the decoder unit.

6. Costs

The cost of the necessary equipment must be taken into consideration if digitization is contemplated, but it must be remembered that offsetting the capital cost of equipment there would be considerable saving of staff time and effort in the analysis of results. Whether this saving is worthwhile depends entirely on the merits of the case concerned and all that can be done here is to indicate roughly how much digitization equipment costs.

Firstly, for trace readers, prices range from about £450 for the simplest version up to between £2,500-£10,000 (depending on the facilities required) for automatic line following equipment. The second trace reader with calibration facilities (para.3, sub-para.2) costs about £1,700. These prices do not include the cost of the final printing equipment e.g. a solenoid operated typewriter would cost about another £360.

The prices of digitizers range from about £130 for the mechanical to nearly £300 for the optical type and standard discs of either type are £20 each, non-standard discs can be obtained at from £100-£200 for the master and £20-40 for each subsequent disc. A relay decoder costs about £150 and the driving units for optical digitizers another £100. Again these prices are exclusive of output. Taking these figures as a basis the cost of basic equipment alone for the digitization scheme suggested above would be about £1,200. This figure includes £400 for the recorder and £360 for a typewriter output.

7. Conclusion

The main conclusion to be drawn is that it is now technically feasible to digitize meteorological information either directly or from chart records. There are limitations on chart sizes and type which can as yet be handled, e.g. so far only strip charts up to six inches in width can be processed.

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Digitization can be applied to the instrument itself either directly or via a suitable servo-amplifying system provided the output of the instrument is suitable, the technique applicable depends on the particular problem involved. There is no doubt that digitization can save considerable time and effort particularly when a large volume of data is to be processed, but whether this saving outweighs the costs of installing the equipment must again be decided on the merits of each particular case.

References

1. A vertical gustiness recorder for use with a captive balloon. J.I.P. Jones. Meteorological Research Papers, Air Ministry, London, No. 974.